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New Strategy Control of Bidirectional Quazi Z Source Inverter with Batteries and Supercapacitors Energy Storage in Grid Connected Photovoltaic System

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ABSTRACT

In this paper, a control of bidirectional Quasi-Z-Source Inverter (qZSI) with energy storage (batteries and supercapacitors) for photovoltaic power generation systems is presented. The quasi-Z-source inverter (qZSI) provides an alternative for the conventional two stages DC-DC/DC-AC photovoltaic (PV) based inverter system. The batteries and supercapacitors are used for compensate the necessitate power occurred in internal or external system parameters circumstances. The main objective of this study is to propose a suitable active and reactive power control for injecting or recovering the power between the electrical grid and PV system (batteries). For adjust the problem of rapid variation of climatic and the power grid conditions, the supercapacitors are controlled with buck-boost converter. Many simulation results obtained using MATLAB/SIMULINK in different rigorous situations show the performance of the proposed system.

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1. INTRODUCTION

With the decrease of conventional energy sources and the growing problem of environmental pollution, the research and utilization of the renewable energy, such as solar energy, wind energy as so on, has been concerned with more and more attention [1]. PV power is becoming more prevalent as its cost is becoming more competitive with traditional power sources. However, the utilization of dedicated energy storage systems needs to be taken into account because of the intermittent nature of the PV generation. Energy storage systems can open the possibility to employ renewable energy sources able to operate in stand-alone mode, grid-connected mode, and mode transitions from stand-alone to grid, or vice versa in micro-grid systems [2].

In conventional structure, the PV grid-connected system is composed in two stages: DC-DC conversion stage to regulate the output voltage from the PV array to certain required level and to extract the maximum power (MPPT), DC-AC conversion stage to produce the usable sinusoidal AC voltage. This topology has many disadvantages such as: more losses, noise, and complexity in control [3]. The Z source inverter (ZSI) [4] offers a simpler single stage inverter topology with several advantages:

a. More boosting capability.
b. Eliminate the shoot through problem.

c. Less components and lower cost.

The quasi-Z-source inverter (qZSI) has some attractive advantages more suitable for application in PV systems. This will make the PV system:

a. Simpler and will lower cost.
b. Able to have the storage system connected in parallel with the capacitive elements. [5]-[8].

For the research on the QZSI with energy storage device, Jorge G. Cintron-Rivera proposes a structure with battery connected in parallel with C_2 [6]. Baoming Ge proposes another topological structure which has a storage battery connected in parallel with C_1. By comparing the two kinds of structure, we find that, for the same inverter output power, the system with C_1 has a wider battery discharging power range than that in the system in C_2. So the topological structure with C_1 is preferable in application of the PV power generation system [5].On the basis of the above research, the topological structure of QZSI with batteries storage which is connected in parallel with C_1 is chosen as the main circuit of the scheme in this paper.

By considering the all above works in this field, the objective of this study is to elaborate a new strategy control of qZSI for ensure a bidirectional power flow between the electrical grid and PV system including batteries and supercapacitors. With the rapidly variation of the external parameters and the reference power demanded by grid and for obtained a good storage dynamics performance, the supercapacitors is integrated in this system, these latter, presente rapidly storage response time, so we can improve the system reliability face the all operation conditions. The basic structure of the studied system is established in Figure 1.

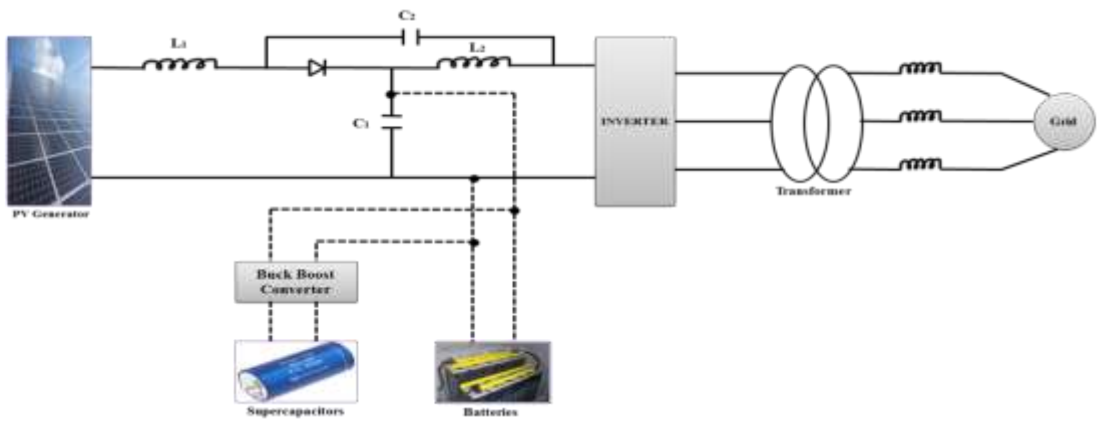


Figure 1. The Proposed system

2. PRINCIPE OF QUAZI Z SOURCE INVETER

The topological structure of QZSI with storage systems (batteries and supercapacitors) which is connected in parallel with C_1 is shown in Figure 2.

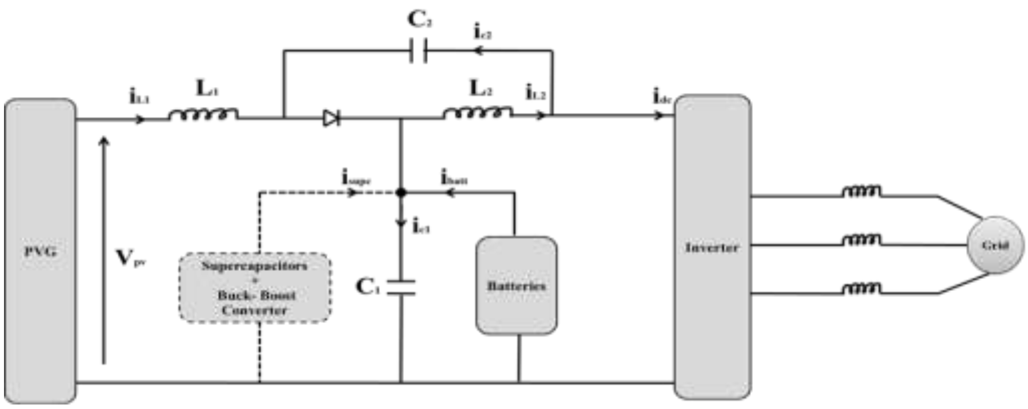
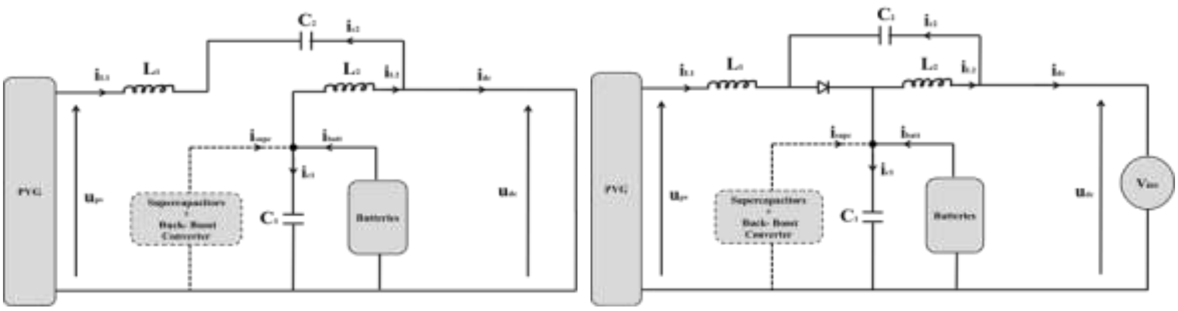


Figure 2. Schema of Quazi Z source inverter with batteries and supercapacitors

There are two working states for the battery-assisted QZSI, i.e., shoot-through state and non shoot-through state. Their equivalent circuits are shown in Figure 3.



(a) Shoot- through (b) Non shoot- through

Figure 3. The two operating mode of Quazi Z source inverter

In the shoot-through state of Figure 3a, the diode will be cut off, and the DC source and capacitors charge the two inductors at the same time.The state space equations of this case are shown in equation 1. In other hand, in the non shoot-through state, as Figure 3b shows, the inverter will be operated as a traditional VSI which is controlled by six active vectors and two traditional zero vectors. The equation 2 represente this case.

$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = u_{pv} + u_{C2} \\ L_2 \dfrac{di_{L2}}{dt} = u_{C1} \\ C_1 \dfrac{du_{C1}}{dt} = i_{batt} - i_{L2} + i_{\text{supc}} \\ C_2 \dfrac{du_{C2}}{dt} = -i_{L1} \end{cases} \tag{1}$$

$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = u_{pv} - u_{C1} \\ L_2 \dfrac{di_{L2}}{dt} = -u_{C2} \\ C_1 \dfrac{du_{C1}}{dt} = i_{L1} + i_{batt} + i_{\text{supc}} - i_{dc} \\ C_2 \dfrac{du_{C2}}{dt} = i_{L2} - i_{dc} \end{cases} \tag{2}$$

We define T_0 as the time interval for shoot through mode and T_1 as the time interval for non shoot through mode, with a switching cycle T_2. The shoot-through duty ratio is then defined as $D = T_0/T_2$, and $T_2 = T_0 + T_1$.The equation system become such as:

$$\begin{cases} c_1 \dfrac{du_{c1}}{dt} = i_{batt} + i_{\text{supc}} + (1-D)i_{L1} - Di_{L2} + (D-1)i_{dc} \\ c_2 \dfrac{du_{c2}}{dt} = (1-D)i_{L2} - Di_{L1} + (D-1)i_{dc} \\ L_1 \dfrac{di_{L1}}{dt} = u_{pv} + Du_{c2} + (D-1)u_{c1} \\ L_2 \dfrac{di_{L2}}{dt} = Du_{c1} + (D-1)u_{c2} \end{cases} \tag{3}$$

In the steady state, the average voltage of the inductors and the current of the capacitances over one switching cycle are both zero. According to (3), we can obtain:

$$u_{C1}=\frac{1-D}{1-2D}u_{pv} \quad , \quad u_{C2}=\frac{D}{1-2D}u_{pv} \tag{4}$$

$$i_B=i_{L2}-i_{L1}-i_{\mathrm{sup}c} \tag{5}$$

The DC-link voltage average value is:

$$V_{dc}=u_{C1}=\frac{1-D}{1-2D}u_{pv} \tag{6}$$

In this system we are three power flows are controlled, the four one automatically matches the power difference through using:

$$P_{batt}=P_{grid}-P_{pv}-P_{\mathrm{sup}c} \tag{7}$$

3. PRINCIPE OF CONTROL

The control block diagram of the PV grid-connected and energy storage system (batteries and supercapacitors) based on Quasi-Z-source inverter is shown in Figure 4.

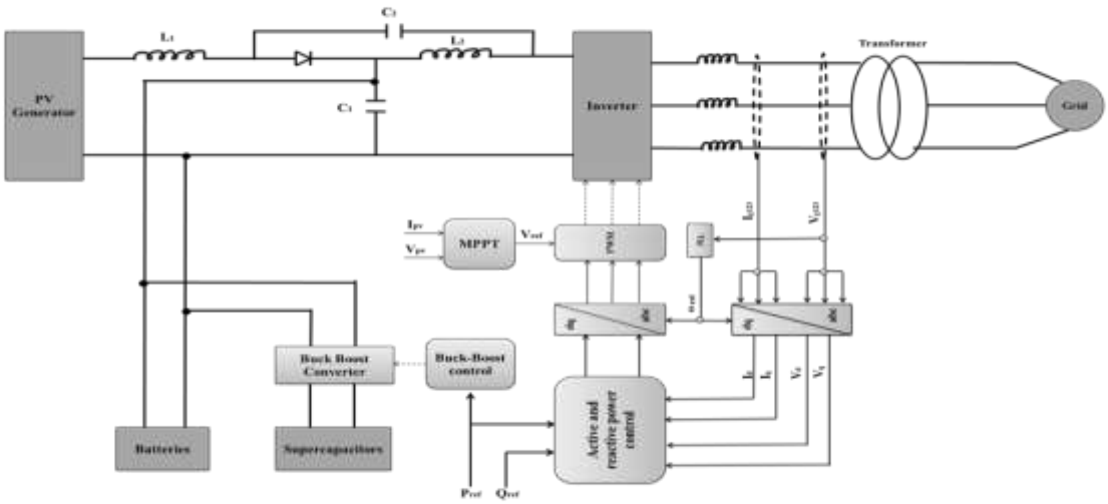


Figure 4. Bloc control of the PV grid-connected QZSI with batteries and supercapacitors system storage

3.1. MPPT control

When ignoring the voltage drop on the internal resistance, the voltage u_{C1} is approximate to the battery voltage $V_{batt,}$ so from (6), we obtain [5],[6]:

$$V_{batt}=u_{C1}=\frac{1-D}{1-2D}u_{pv} \qquad \text{So:} \qquad u_{pv}=\frac{1-2D}{1-D}V_{batt} \tag{8}$$

From (8) we find:

a. By varying the shoot through time over one switching cycle, the input voltage can be boosted accordingly.

b. The input voltage V_{pv} increases when the shoot-through time is decreased, and decreases when the shoot-through time is increased.
c. The maximum power point voltage can be tracked by adjusting the shoot-through duty ratio.

The perturbation and observation (P&O) method is one of the common maximum power point tracking control methods. In this technique, first the PV voltage and current are measured and hence the corresponding power P_1 is calculated. Considering a small perturbation of voltage in one direction corresponding power P_2 is calculated. P_2 is then compared with P_1. If P_2 is more than P_1, then the perturbation is in the correct direction; otherwise it should be reversed. In this way, the peak power point is recognized and hence the corresponding voltage (V_{opt} =V_{ref}) can be determinate [9]-[12].

3.2 Quazi Z source inveter

In the same way as the conventional voltage-source inverter, the output power of the qZSI can be controlled on the basis of the $d-q$ model [5],[13]-[16]. The control bloc is shown in Figure 5.

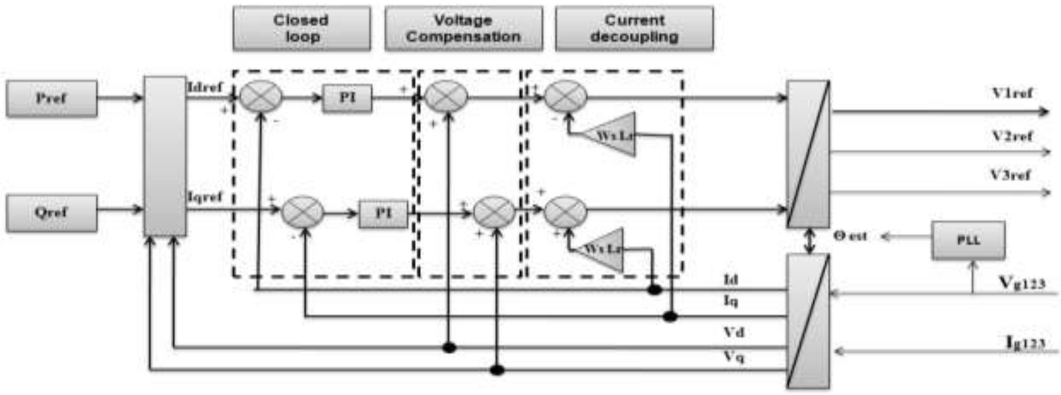


Figure 5. d-q active and reactive control power

The active and reactive power (P, Q) can be both expressed by using Park components of supply voltage (V_d ,V_q) and line current (I_d , I_q). Therefore, the reference currents (I_{dref}, I_{qref}) which allow setting the desired reference active and reactive powers (P_{ref}, Q_{ref}), as follows:

$$\begin{cases} P = V_d I_d + V_q I_q \\ Q = V_d I_q - V_q I_d \end{cases} \quad \text{So} \quad \begin{cases} I_{dref} = \dfrac{P_{ref} V_d - Q_{ref} V_q}{V_d^{\,2} + V_q^{\,2}} \\ I_{qref} = \dfrac{P_{ref} V_q - Q_{ref} V_d}{V_d^{\,2} + V_q^{\,2}} \end{cases} \tag{9}$$

The simple boost control [4],[17]-[20] for qZSI is used to integrate the duty ratio D and three-phase voltage in the sinusoidal pulse width modulation PWM, the Figure 6 illustrate the control bloc.

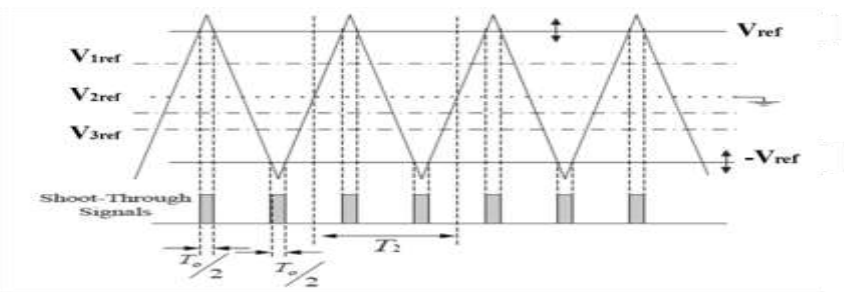


Figure 6. Bloc of integrate duty ratio in PWM modulation

The PV voltage reference becomes the shoot-through reference signal V_{ref}. If V_{ref} is lower than the carrier signal, then all the switches in the three arms will be in the on position. Also if V_{ref} is higher than the carrier signal, then all the switches will be in the on position.

3.3. Buck boost control

The DC/DC bidirectional converter (buck-boost converter) used for controlling the supercapacitors storage system is shown in Figure 7.

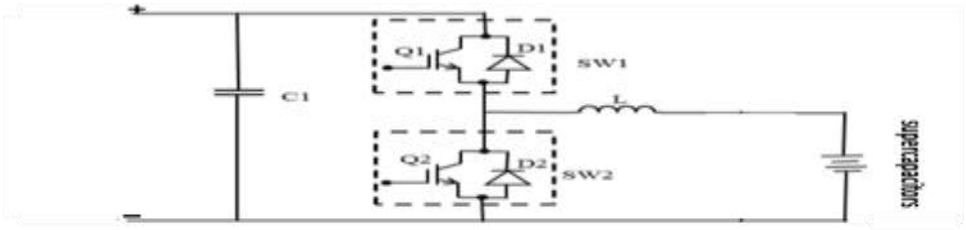
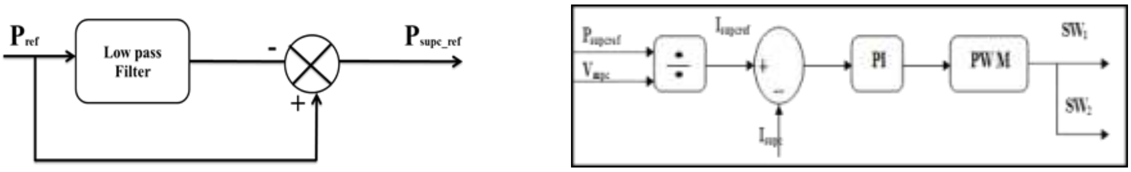


Figure 7. Bidirectional DC/DC converter

The supercapacitors power is given such as [15],[21],[22]:

$$P_{supc} = V_{supc} I_{supc} \quad , \quad I_{supc\_ref} = \frac{P_{supc\_ref}}{V_{supc}} \tag{10}$$

The reference power of the supercapacitors P_{supc_ref} is calculated from the reference active power such as mentioned in Figure 8a. So the control used is given in Figure 8b.



a. the supercapacitors reference power

b. supercapacitors buck boost controls

Figure 8. Supercapacitors control

4. SIMULATION RESULTS

The simulation is carried out with MATLAB/SIMULINK to evaluate our system behavior based on the two storage elements (batteries and supercapacitors). Several numeric simulations are accomplished for different situations (PV power produced, power injected). Table 1 shows the values of important element.

Table 1. Parameter Values

ELEMENT	Values
Max PV power (P_{pvmax}) (kW)	5.6
Batteries voltage (V_{batt}) (V)	12*34
Supercapacitors voltage (V_{supc}) (V)	2.7*100
Transformer (Y/Y) (V)	220/380
Electric grid (V)	220/380
Switching frequency (kHz)	10

The simulation is achieved in 2.5s, because the limitation memory. Figure 10 shows the PV power obtained from the array for various illuminations and temperature of 25°C. The MPPT is able to track the

maximum power level at different illuminations with acceptable dynamic response. During the period of 1000 W/m^2 we can obtain the maximum power of 5.6 kW. When the produced photovoltaic energy is higher than the reference imposed, it on more energy is stored in the batteries, in the contrary case the battery intervenes; therefore we have transfer of pbattery power to the electrical grid, like demonstarated in the system power flow of Figure 9 and Figure 16.

The Figure 12 and Figure 15 improves that the control device makes it possible to impose the values desired of injected currents and active and reactive powers with a very good dynamics. In other hand, we can transit the active power P_{grid} with a QZSI from electric grid to the storage system (batteries). In Figure 11 because the reactive power imposed (Q_{ref}=0), the interval between the voltage and current is null in case of injected power or recovred, so the power factor is maintain 1.

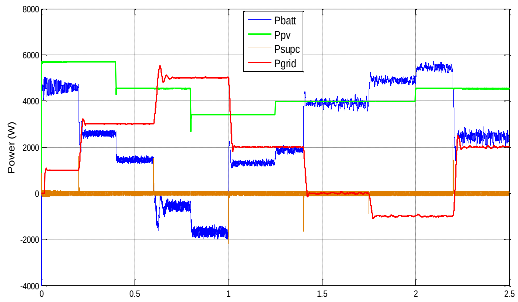


Figure 9. Power flow

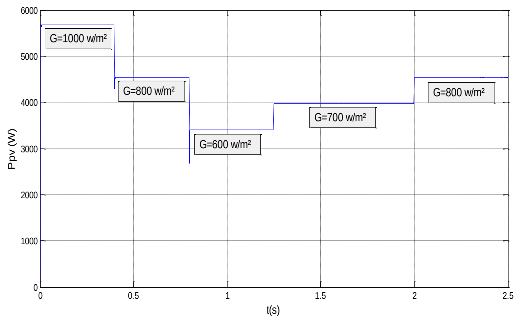


Figure 10. PV power for variable illumination

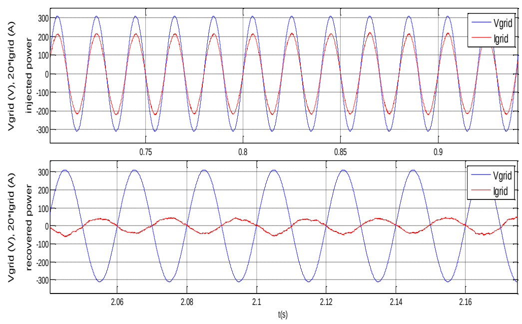


Figure 11. Voltage and grid current

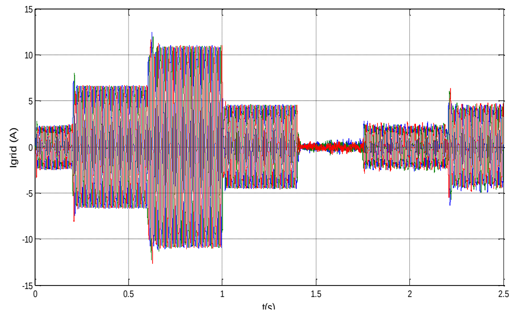


Figure 12. Form of the current injected to the grid

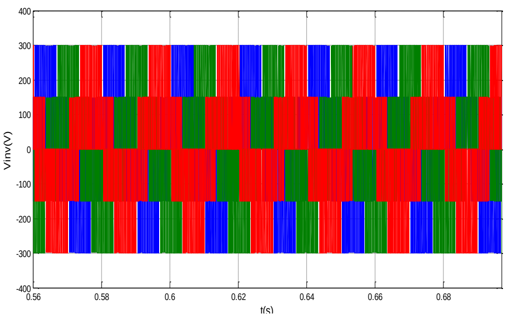


Figure 13. Simple three phase voltage of QZ inveter

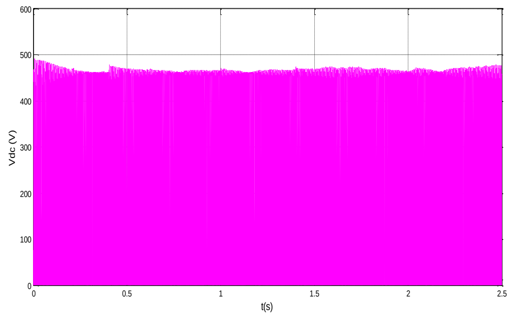


Figure 14. DC link of QZ inverter

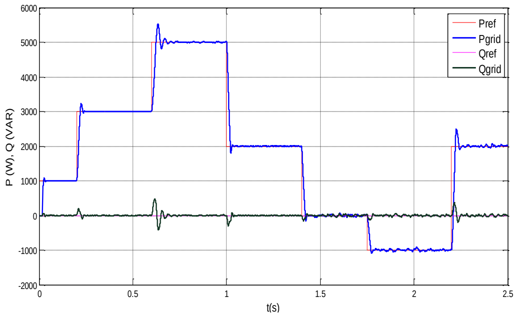


Figure 15. Active and reactive power injected to the grid

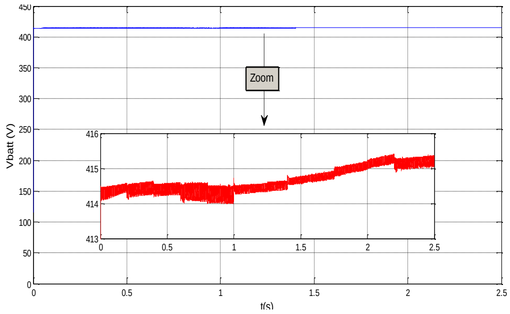


Figure 16. Batteries voltage

When the storage power reference is imposed, the batteries power follow the permanent regime mode because it has a long constant time, in other way the Supercapacitors power pursue the a transient mode of the imposed active power in any conditions like show in Figure 17 and Figure 18.

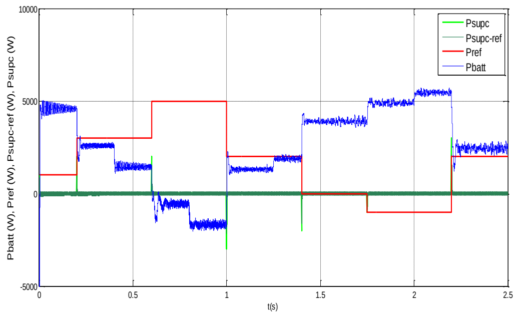


Figure 17. Reference and supercapacitors power

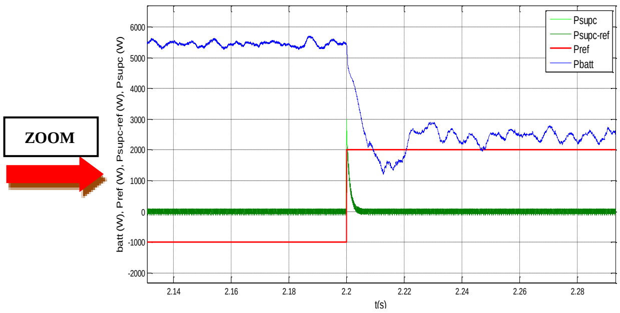


Figure 18. Reference and supercapacitors power

Comaped with other previous studies, the all results presented show and confirm that the control strategy adopted with two storage systems (batteries and supercapacitors) makes it possible to manage the power flow exchanged with haigh flexibility degres in all conditions with very good performances.

5. CONCLUSION

The paper present the design, modeling and control of bidirectional qZSI inverter with batteries and supercapacitors system storage in grid connected photovoltaic installations. The grid-connected power injection was fulfilled with P-Q decoupled control with maximum power point tracking of the PV panels integrated by a simple boost method used in qZSI. When the output power of photovoltaic panels is greater than the grid-connected power, the surplus power is absorbed by the storage batteries. In the contrary case, the lack of power is supplemented by the storage battery. Then good performance of the grid-connected current is achieved. In other hand, for acquire a good storage dynamics performance, supercapacitors have a fast response time, thus we incorporate it in our system, the control is adopted with bidirectional buck-boost converter for reimburse a transitory period time of the reference power in all conditions. The simulations results obtained in many rigorous conditions confirm the viability and validity of the proposed system and control strategy.

REFERENCES

[1] W. Cai, *et al.*, "Analysis and simulation for grid-connected photovoltaic system based on Matlab," *IEEE*, 2011.
[2] S. M. Park and S. Y. Park, "Power weakening control of the photovoltaic- battery system for seamless energy transfer in microgrids," *IEEE*, 2013.
[3] Z. Rasin and M. F. Rahman, "Design and Simulation of Quasi-Z Source Grid connected PV Inverter with Battery Storage," *IEEE*, 2012.
[4] F. Z. Peng, "Z-Source Inverter," *IEEE transactions on industry applications*, vol/issue: 39(2), 2003.

[5] G. Baoming, *et al.*, "An Energy-Stored Quasi-Z-Source Inverter for Application to Photovoltaic Power System," *IEEE Transactions on Industrial Electronics*, vol/issue: 60(10), 2013.
[6] J. G. C. Rivera, *et al.*, "Quasi-Z-Source Inverter with Energy Storage for Photovoltaic Power Generation Systems," *IEEE*, 2011.
[7] J. Khajesalehi, *et al.*, "Parallel Operating of Two Energy Storage Battery Systems Using Quasi Z-Source Inverter," *IEEE*, 2014.
[8] Z. Rasin, *et al.*, "Design and Simulation of Quasi-Z-Source Grid connected PV Inverter with Bidirectional Power Flow for Battery Storage Management," *IEEE*, 2013.
[9] M. Khelif, *et al.*, "Simulation, optimization and performance analysis of an analog, easy to implement, perturb and observe MPPT technique to be used in a 1.5 kWp photovoltaic system," *IRSEC*, 2013.
[10] B. Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," *IEEE Transactions on Sustainable Energy*, vol/issue: 4(1), 2013.
[11] P. Shunmugakani and D. Kirubakaran, "Simulation and Implementation of Quasi-Z-Source Based Single-stage Buck/boost Inverter Fed Induction Motor," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol/issue: 7(2), pp. 369-378, 2016.
[12] T. K. S Sathayanarayanan, *et al.*, "Modelling, Impedance Design, and Efficiency Analysis of Battery Assists PV tied Quasi-Z source inverter," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol/issue: 7(3), 2016.
[13] H. Fakham, *et al.*, "Power Control Design of a battery charger in a Hybrid Active PV generator for load following applications," *IEEE Transaction on Industrial Electronics*, vol/issue: 58(1), pp. 85-94, 2011.
[14] D. Sun, *et al.*, "An Energy Stored Quasi-Z Source Cascade Multilevel Inverter Based Photovoltaic Power Generation System," *IEEE Transactions on Industrial Electronics*, 2015.
[15] Y. Liu, *et al.*, "Control System Design of Battery-Assisted Quasi-Z-Source Inverter for Grid-Tie Photovoltaic Power Generation," *IEEE Transactions on Sustainable Energy*, vol/issue: 4(4), 2013.
[16] A. Zakerian and D. Nazarpour, "New Hybrid Structure Based on Improved Switched Inductor Z-Source and Parallel Inverters for Renewable Energy Systems," *International Journal of Power Electronics and Drive Systems* (*IJPEDS*), vol/issue: 6(3), pp. 636-647, 2015.
[17] J. H. Park, *et al.*, "Power Conditioning System for a Grid Connected PV Power Generation Using a Quasi-Z-Source Inverter," *Journal of Power Electronics*, vol/issue: 10(1), 2010.
[18] B. Su, *et al.*, "Research on the Composite Control for PV Grid-connected and Energy-storage based on Quasi-Z-source inverter," *IEEE*, 2014.
[19] S. Thangaprakash, "Unified MPPT Control Strategy for Z-Source Inverter Based Photovoltaic Power Conversion Systems," *Journal of Power Electronics*, vol/issue: 12(1), 2012.
[20] G. Prakash and C. Subramani, "Space Vector and Sinusoidal Pulse Width Modulation of Quasi Z-Source Inverter for Photovoltaic System," *International Journal of Power Electronics and Drive Systems*, vol/issue: 7(3), 2016.
[21] X. Liu, *et al.*, "Control of Hybrid Battery/Ultra-capacitor Energy Storage for Stand-alone Photovoltaic System," *IEEE*, 2010.
[22] Q. Kang, *et al.*, "Energy management in grid connected PV systems with supercapacitors energy storage," *IEEE*, pp. 1-5, 2011.

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